The cracks at all for corners were repaired by drilling holes typically 16-mm in diameter. For the larger cracks, the hole size was increased to a 25-mm diameter. With the holes drilled, testing continued and no further cracking was noticed even after an additional 10 million cycles were applied. This number of cycles is approximately four times the number of cycles that previously initiated and propagated the termination cracks. Therefore, this repair method is highly recommended in areas where a hole may be tolerated and cracking is intiated due to high local constraint.

11.4 BASE METAL CRACK IN ADDED WEB

Previously it was mentioned that the webs of the specimens did not always line up with the added web. This presented a problem when attaching the splice plates between the specimen and the added web. An in-line connection was achieved by placing spacer plates between the splice plates and the webs.

At one location, the southeast corner, the alignment of the webs was off as much as 13-mm. When the spacer plates were used at this location, the slip-critical connection was poor and a crack initiated at the last bolt hole within 50,000 cycles. The crack quickly propagated through the entire added web and into the beam flange. Figure 11-14 shows the location being discussed.

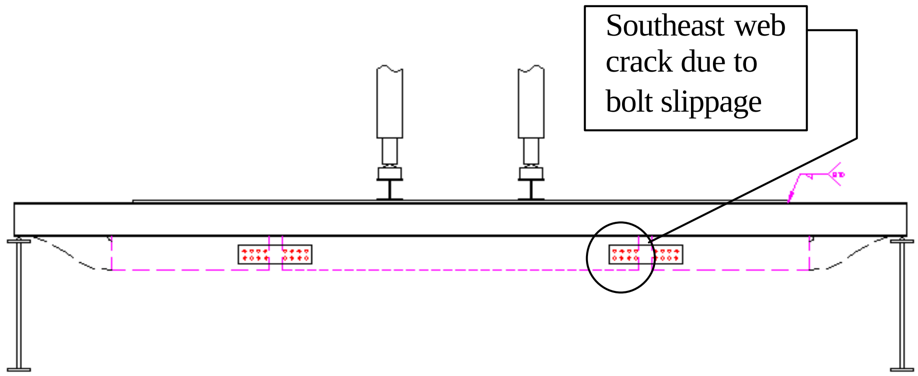

Figure 11-14: Area where clamping force in slip-critical connection was poor.

A simulation of the crack location may be seen in Figure 11-15 (A simulation is used because no appropriate photo is available of the actual corner where the crack occurred.) A closer view of the initial crack is presented in Figure 11-16.

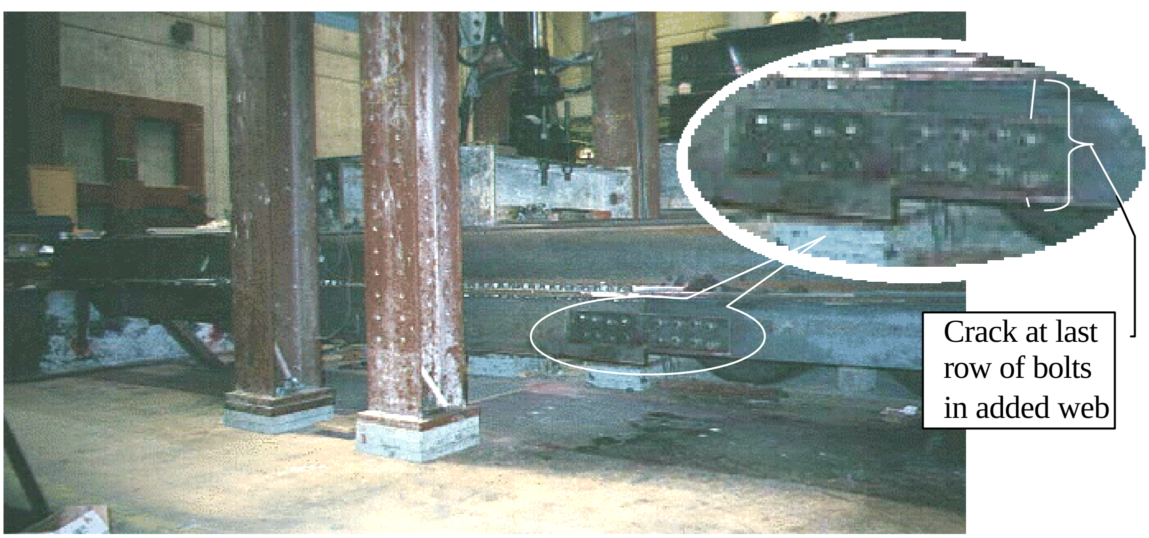

Figure 11-15: Detail of crack occurring in full penetration weld with tips drilled out.

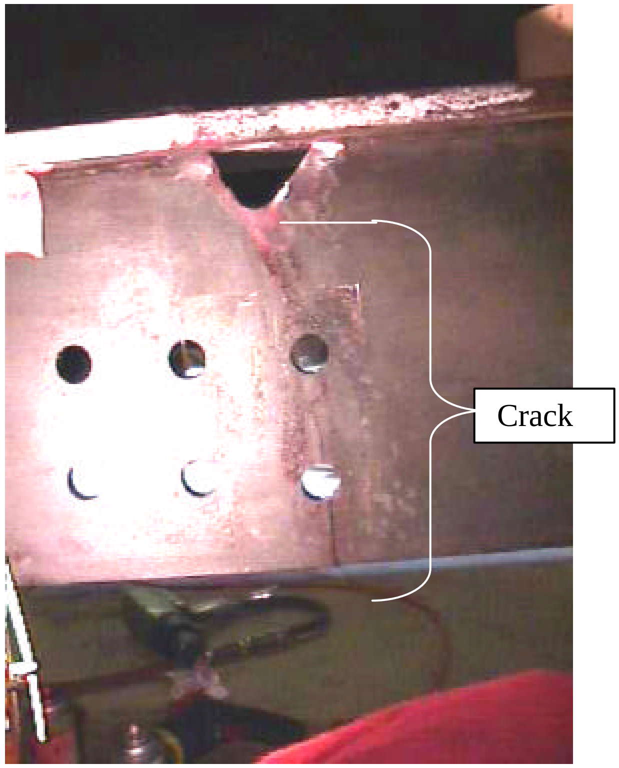

Figure 11-16: Detail of crack in added web with weld access hole already prepared.

The repair was made similarly to the first repair discussed: First drilling out the crack tips, then cutting in a weld access hole, arc-gouging the crack faces, and finally making a complete penetration butt weld between the cracked faces. This repair was accompanied by adding 3 rows of bolts and a longer splice plate.

A series of photographs detail this repair. Figure 11-18 shows the holes drilled in the bottom flange of the support beam to remove the crack tips. A broader view of the area may be seen in Figure 11-19. The weld access hole has also been roughly cut in with a reciprocating saw. One may also notice the arc-gouged crack in preparation for a complete penetration weld. Arc-gouging the crack faces was found to be a useful technique for both tracing the crack line and preparing the detail for a butt weld. Grinding is the alternative method of preparing for the butt weld, but tracking the crack can be extremely difficult when an abrasive wheel is used to remove material. A closer view of the prepared crack and drilled holes may be seen in Figure 11-17.

Figure 11-18: Crack faces arc-gouged and crack tips drilled.

Figure 11-17: Detail of crack at prepared weld access hole prior to welding.

The entire length of the crack would be gouged to mid-thickness prior to welding two crack faces together. After this first weld was made, the opposite side was back-gouged and welded so no trace of the previous crack existed within the weld.

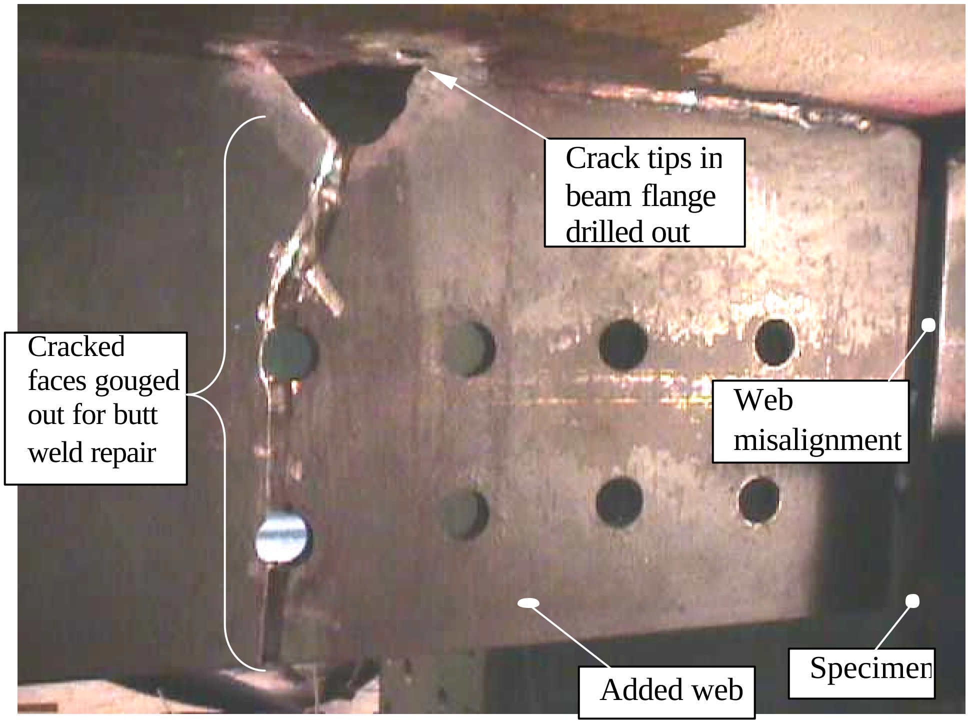

Figure 11-19: Full view of cracked area prior to weld repair.

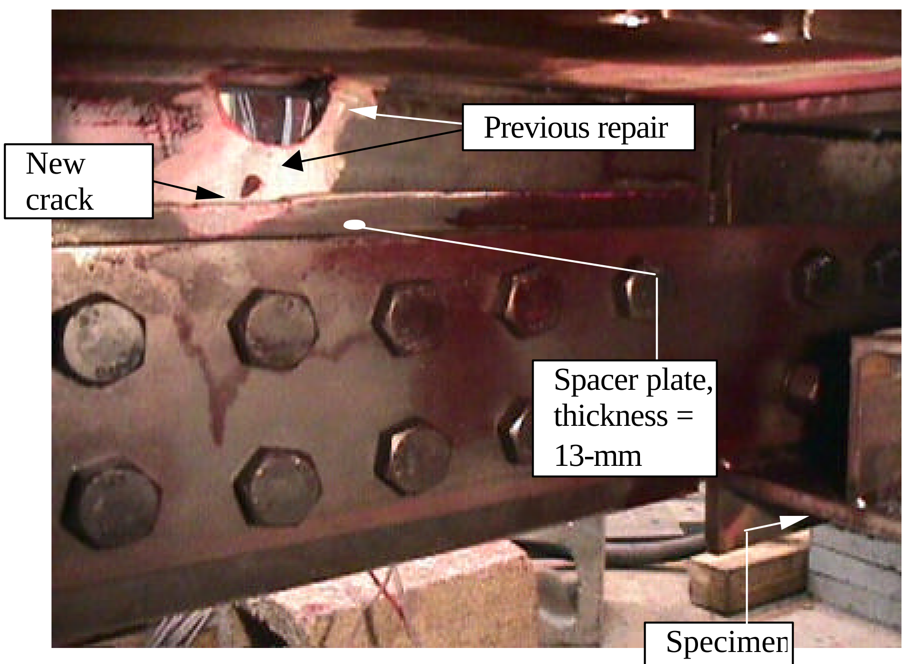

Figure 11-20: Full view of repaired crack.

The repair with the splice plates attached is shown in Figure 11-20. Notice the splice plates were extended to overlap the previously cracked area.

This repair was successful only as a temporary solution. Cracks repeatedly emerged from the weld access hole, the bolt holes, or a defect in the butt weld itself (See Figure 11-21). These cracks were allowed to propagate if they were contained to the added web for the duration of the particular specimen's test.

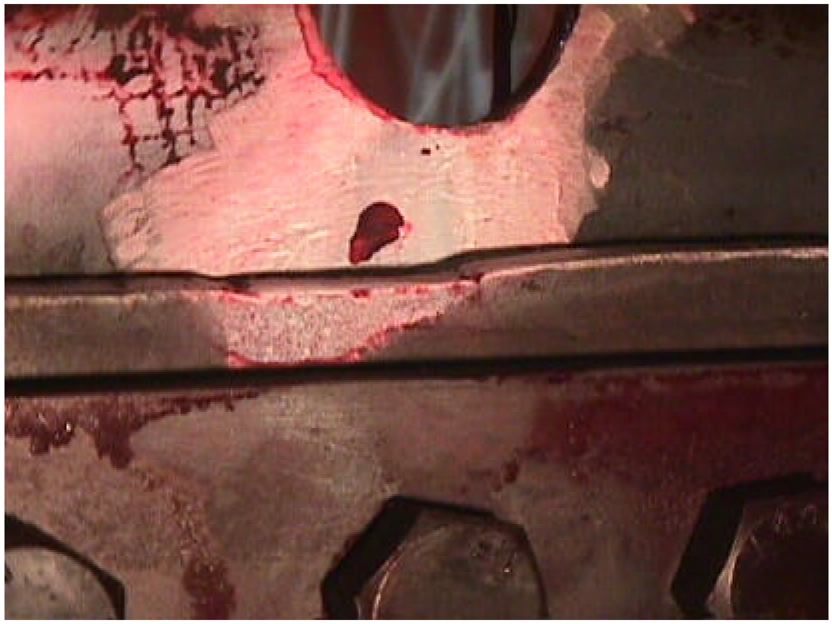

Figure 11-21: Re-initiation of crack from internal weld defect.

A new repair was made at the time specimens were changed. The repair was repeated four times during the span of the testing schedule. After the second repair, a strain gage was mounted 3-cm below the weld access hole. The stress range at this location was measured to be 80 MPa. At this stress range, new cracks emerged reliably at one million cycles after each repair. A record of the crack recurrence at this location may be seen in Table 11-3. The crack lengths and number of cycles shown correspond to the point at which the cracks were first noticed.

Table 11-3: Cracking in butt weld repair at splice location.

Crack Description (Weld access hole = W.A.H.)	Crack Length (mm)	Estimated Stress Range	Estimated Number of Cycles	Repair Method
From bolt hole due to slipping	134	60 MPa	0.4×10^5	Full repair as described above
1st butt weld repair, from bolt hole	25	80 MPa	9.8×10^5	
2nd butt weld repair, from crack at W.A.H.	19	80 MPa	1.0×10^5	
3rd butt weld repair, from butt weld defect	8	80 MPa	1.3×10^5	
4th butt weld repair, from W.A.H.	12	80 MPa	1.1×10^5	

11.5 SPLICE PLATE CRACKING

Cracking occurred in the splice plates for a variety of reasons despite being over-designed for the theoretical conditions. For the majority of the cracking incidents, the misalignment of the specimen web and the added web played a major role in crack initiation. Splice plate failure occurred a number of times and the failures can be categorized in one of three categories:

A) Crack initiation due to ineffective clamping force
B) Crack initiation due to high tensile stress ranges
C) Crack initiation due to rubbing

These three cases may be seen in Figure 11-22. A close view of the fatigue crack surface in case B is shown in the photo on the right (Figure 11-23).

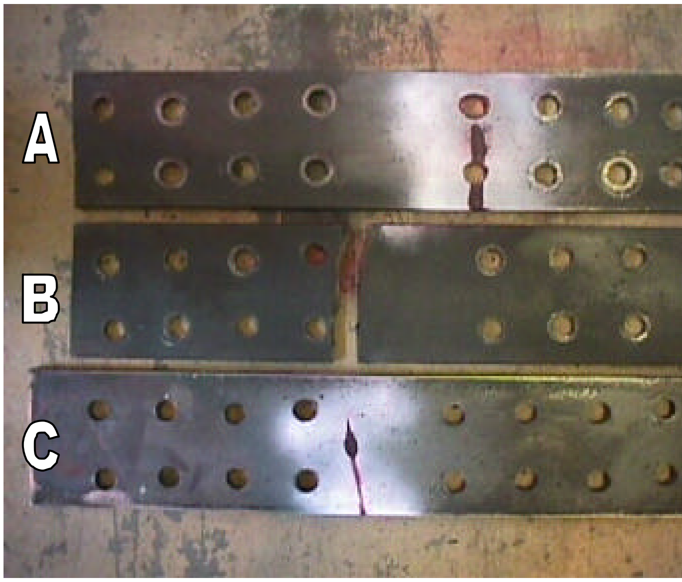

Figure 11-22: Various cracks observed in splice plates

Figure 11-23: Fatigue striations on crack faces of Case B.

Case A can be attributed to both web misalignment and improper clamping force. The slight misalignment of the webs, even with spacer plates, induced a small amount of prying when tensile load was applied. This prying action prevented the first row of bolts from sufficiently providing a slip-critical connection. Without a slip-critical connection, the bolted tension member drops from a Category B detail to a Category D detail. Such a shift represents a 56 percent reduction in the constant amplitude fatigue limit.

Case B has occurred for similar reasons to that of Case A. Web misalignment probably induced loading other than pure tension. In this case, however, the crack did not initiate at the bolt hole. For this reason, it is believed that cracking in splice plates at other locations in the frame increased the loading demands placed on splice plate B. The failure is seen as a pure base metal failure, a Category A detail (AISC Steel Design Manual). Category A details have a constant amplitude fatigue limit (CAFL) 50 percent higher than that of a slip-critical connection. The development of this type of crack indicates that a large amount of load shedding to this detail occurred when the other splice plates cracked.

Case C is the direct result of rubbing between the splice plate and one of the webs it connected. The rubbing initiation is recognized because the crack initiated in the gap between the specimen and the added web.

Usually splice plates were discarded and replaced with newly drilled plate steel. After the initial cracking, the splice plate thickness was increased 50 percent at all locations. This was the maximum thickness which could be tolerated in the setup because the exterior stiffeners were closely spaced next to the edge web. The actual clearance was 10-cm and may be seen in Figure 11-24.

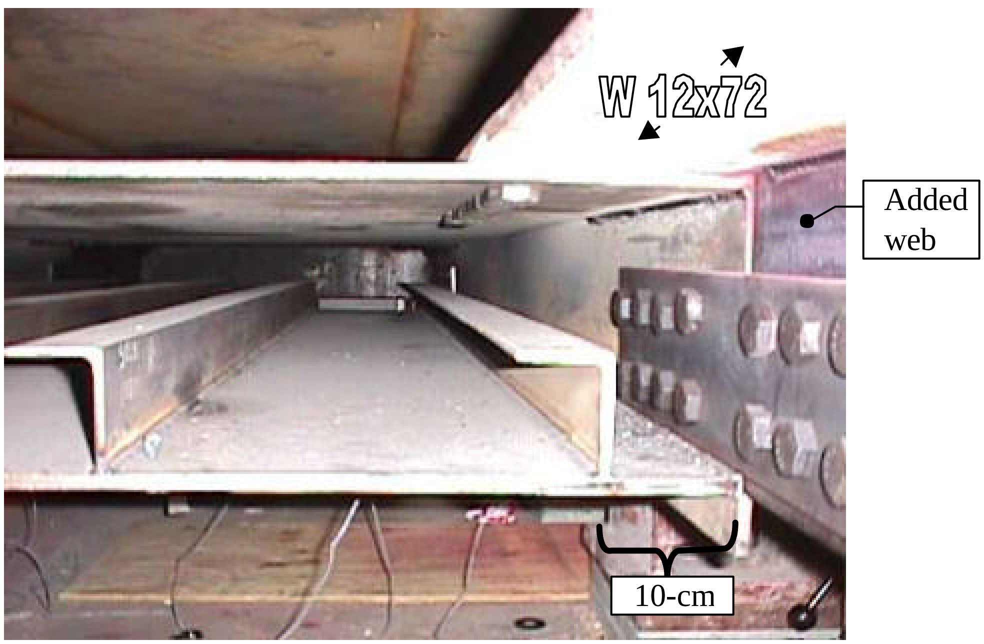

Figure 11-24: Tight clearances for bolting splice plates.

Even with the increased thickness all of these cracks reocurred. In several of the plates it was decided to show the effectiveness of the previously described welding repair technique. The repair was made similarly to the other weld repairs: Finding and drilling out the crack tip, weld repairing the crack, and re-drilling the weld termination to provide a clean termination. The performance of the repaired plate was very good and the plate was able to be re-used as shown in Figure 11-25. Poorer performance was seen in the repair of plates with cracks emanating from bolt holes. In these repairs, the weld terminated in an active bolt hole which had to be oversized to provide the clean weld termination. Oversizing, however, reduced the capacity at that particular location and cracking re-initiated at the bolt hole at approximately 800,000 cycles.

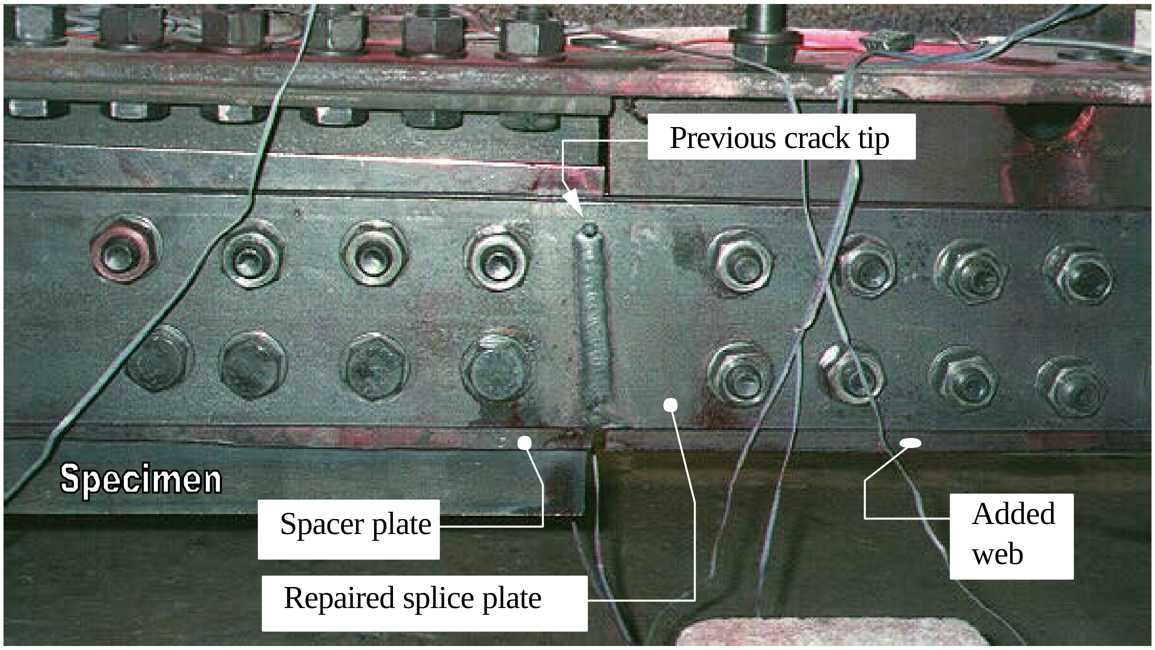

Figure 11-25: Repaired splice plate assembled in test setup.

11.6 COVER PLATE CRACKING

The support structure boasted a 19-mm thick cover plate that was fillet welded to parallel W12x72 beams. The cover plate was attached continuously to the beams by 8-mm fillet welds with E70 weld material. During the testing of the second specimen, a large crack was noticed at the southwest corner of the structure. The crack discovered had propagated to almost the full width of the beam flange and had penetrated the beam web. Cracking was not noticed at the other cover plate termination locations, however. Figure 11-26 illustrates the crack propagation direction and cover plate detail, and Table 11-4 documents the crack history.

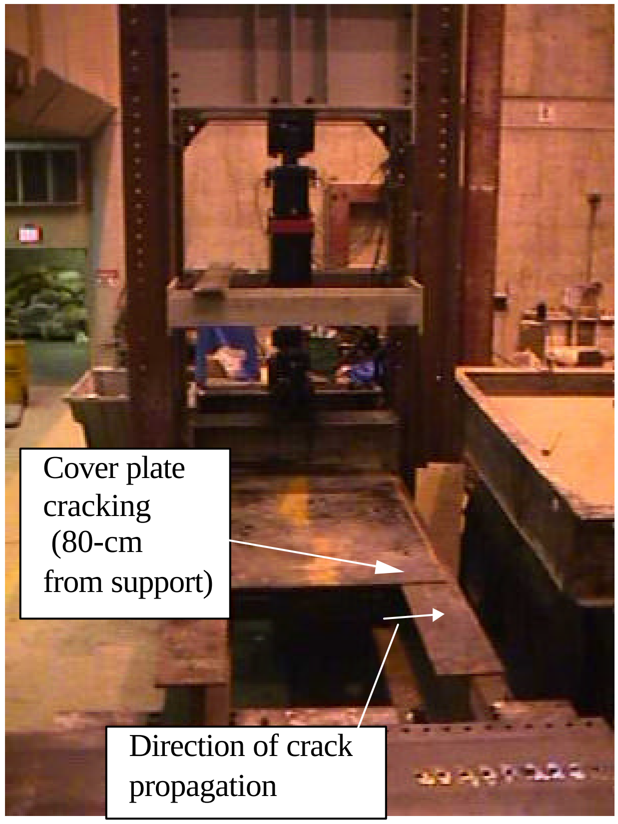

Figure 11-26: Cover plate detail prior to repair with and crack propagation direction indicated.

Table 11-4: Cracking at end of cover plate.

Crack Description	Crack Length (mm)	Estimated Stress Range	Estimated Number of Cycles	Repair Method
Fillet weld termination (Category E detail)	267-mm in beam flange, 37-mm in beam web	20 MPa nominal	$3.4x10^6$	Gouge crack path and butt weld, drill out crack tip, add section transition

The repair to the cover plate crack involved completely gouging out the cracked area and welding the crack faces with a full-penetration, one-sided weld. In the web, the cracked area was completely removed and a large opening was created to erase any presence of sharp discontinuities. Once the compression flange of the beam was repaired, the cover plate was extended with both a rectangular and triangular plate addition. The cover plate extension may be seen in Figure 11-27.

Figure 11-27: Plates added to smooth transition of cover plate width.

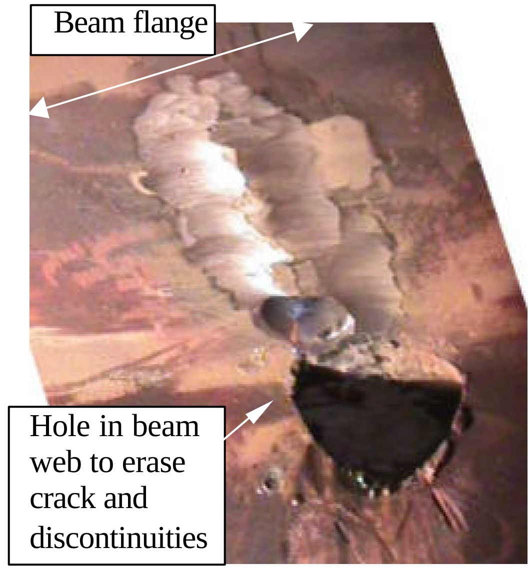

Figure 11-28: Gouged hole in beam web to erase crack tips.

The triangular section was the source of small fatigue cracks after 500,000 cycles at the point where it connected with the rectangular plate. These cracks were successfully ground out and then the triangular piece was ground to a smooth contour as seen in Figure 11-27 and Figure 11-28. After one million cycles, cracks re-emerged from defects in the butt weld and holes were drilled, as seen in Figure 11-29, to contain the crack to a small region.

Figure 11-29: Holes drilled to contain crack propagating from internal weld defect.

The cover plate extensions were provided on the east side of the support structure only. On the west side, surface cracks were found at both north and south transverse fillet welds. These surface cracks were each 76-mm long and had not progressed the full depth of the fillet weld. Instead of a more costly repair performed on the east end, peening was used with an air-powered impact chisel. The toe of the transverse fillet weld was thoroughly hammered with the impact chisel, making a 3-mm depression in the base metal and weld material. The surface crack at the toe of the weld never re-appeared. However, a small surface crack appeared mid-way in the testing in the fillet weld exterior surface. To repair this crack, the impact chisel was used over the entire transverse fillet weld and part of the longitudinal weld. This operation successfully erased all incidence of cracking for the remainder of the testing (~7 million additional cycles) at the west end cover plate terminations. Such success re-iterates the well-known benefits of peening in fatigue-sensitive areas.